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ABSTRACT

Fault Tree Analysis (FTA) is a method of examing communication in an organization by focusing on: (1) the complex interrelationships in human systems, particularly in communication systems; (2) interactions across subsystems and system boundaries; and (3) the need to select and "prioritize" channels which will eliminate noise in the system and maximize effectiveness. FTA provides a step-by-step description of possible failure events within a system and the interactions (the combination of potential occurrences) which could result in a predetermined undesirable event. The FTA technique begins with the description of the system as it exists and proceeds through identification and analysis of potential failures to final suggestions for system changes or modifications. The technique focuses not only on how an organization is designed to operate but also on how it does operate in practice. (A series of diagrams is included in the description of the process.) (RN)

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A FAULT TREE APPROACH TO ANALYSIS OF ORGANIZATIONAL COMMUNICATION SYSTEMS

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Theoretical Framework

An organization may be thought of as an association of interdependent parts working toward some end. If this end can be interpreted as being purposeful and the association considered an interaction, then the result essentially represents a common definition of a system, namely, a purposeful set of interdependent interaction subsystems, or parts. In this paper a system approach will be used as the framework for analysis of the communications which reflect the interdependencies and interactions among subsystems or parts of organizational systems.

An organizational communication system, then, consists of those interdependencies and interactions among and within subsystems, through the act of communication, which serve the purposes of the organization. We will be regarding communication, not just in the sense of the exchange of information, but as the basic means of social interaction.

In its simplest sense, a system may be described by the following model:

Fig. 1

The rectangle represents the performance function or structural unit of interest, which may be as small as a single component (in a hardware system), or an individual, or it may be a subsystem or a collection of subsystems. Inputs to the unit are either energy or information from other parts of the system, which are then processed within the unit, resulting in outputs to other parts of the system. The feedback control provides a match between outputs and inputs, which, in closed systems, is designed to maintain system equilibrium.

Any subsystem or the total system can be depicted by elaborations of the diagram in Figure 1. Variations of the functional flow block diagram in Figure 2 are useful for this purpose.

Fig. 2

Social systems, of which organizational systems are a type, generally receive their valued targets from outside the system. This is particularly true of educational systems, which must be responsive to the needs and wishes of the larger society. The current public demand for "accountability" in education is a demonstration of this fact. Typically, then, organizational systems have at least some exchange of information and/or energy with the environment. There is thus the need to balance the homeostatic nature of the closed-loop system with the disequilibrious nature of the open system responding to its environment.

Katz and Kahn (1971) point out that social systems are restricted communication networks, that human organizations are informational as well as energic systems, and that every organization must take in and utilize information. Conversely, the intake and distribution of information are also energic processes. The closer one gets to the organizational center of control and decision making, the more pronounced is the emphasis on information exchange.

Katz and Kahn state:

> In this sense, communication--the exchange of information and the transmission of meaning--is the very essence of a social system or organization. The input of physical energy is dependent upon information about it, and the input of human energy is made possible through communicative acts. . .Similarly the transformation of energy (the accomplishment of work) depends upon communication between people in each organizational subsystem and upon communication between subsystems. (1971, p. 81)

Because of these interrelationships, the analysis of organizational effectiveness often becomes an analysis of the effectiveness of the communications within an organization. Regardless of the form taken by the analysis, there is often the assumption that communication will be improved if there is a freer flow of information. We commonly assume that many problems, both social and individual, result from faulty or inadequate communication, but this is a grossly simplistic approach. Indeed, problems within organizations may be exacerbated by too much communication. As Katz and Kahn (1971) point out, "In terms of information theory, unrestricted communication produces noise in the system." (p. 84)

A system approach to analysis of communication systems, then, referring back to the model in Figure 1, takes into consideration not only the input-process-output-feedback configuration, but the interaction between subsystems and between the system and its environment. Within an organization there are problems of clear communication across subsystems. Without adequate translation across system boundaries, communications can add to the noise in the system.

> Communication needs to be seen, not as a process occurring between any sender of messages and any potential recipient, but in relation to the social system in which it occurs and the particular function it performs in that system. . .An organized state of affairs, a social system, implies the restriction of communication among its members. . .

> Organizational development sometimes demands the creation of new communication channels. The very nature of a social system, however, implies a selectivity of channels and communicative acts--a mandate to avoid some and to utilize others. (Katz and Kahn, 1971, pp. 82-84)

This matter of selectivity of channels and communication acts poses a problem of considerable difficulty in communication system analysis. This paper will suggest Fault Tree Analysis as a new technique which copes with the following concerns: (1) the complex interrelationships in human systems and particularly in communication systems, (2) the interactions (or interfaces) across subsystem and system boundaries, and (3) the need to select and prioritize channels which will minimize "noise" in the system and maximize system effectiveness.

There are two basic approaches to analysis: (1) analysis in terms of success or accomplishment of system's purpose, or (2) analysis in terms of failure or non-accomplishment of a system's purpose. A system approach may utilize either success or failure analysis.

Analysis in terms of success, however, is much more problematic than analysis in terms of failure. Not only is it difficult to achieve consensus as to those design characteristics and functions, the channels and interactions, which lead to system success, but experience has shown that in complex systems, it is much easier to describe and achieve consensus as to what constitutes failure. When a system is functioning smoothly, it is not at all easy to specify precisely what combinations of events contribute to this happy state. But when breakdowns occur, they are immediately apparent, although their causes and their "downstream" effects may be more obscure.

Fault Tree Analysis (FTA) is a technique for enhancing the probability of success in any system by analyzing the most likely modes of failure that could occur. It provides a logical, step by step description of possible failure events within a system and their interactions--that is, the combinations of potential occurrences which could result in a predetermined undesired event (U.E.) The fault tree was so named because the completed graphic portrayal of a functional system utilizes a branching process analagous to the outline of a coniferous tree.

It is not the intent of this paper to present a detailed explanation of the technique of performing a Fault Tree Analysis. Explanations of both qualitative and quantitative analysis, examples of educational and management information applications, and prototype trees may be found in Witkin with Stephens (1968), Witkin (1970), Stephens (1972), and Witkin (1971).

Description of Fault Tree Analysis

Following is a brief overview of the steps in Fault Tree Analysis. It should be noted that the fault tree approach can be used in a more simplified, abbreviated form, and still be very useful. In fact, decision makers have found that they could derive useful information from any of the following steps. Regardless of the extent or depth of the analysis, however, the communication analyst should work with a team representing all facets of the organization.

1.0 Describe the system to be analyzed, developing a system map or graphic equivalent.

2.0 Identify major stress points through a Fault Hazard Analysis (FHA).

3.0 Perform a Failure Mode and Effect Criticality Analysis (FMECA).

4.0 Perform qualitative fault tree construction.

5.0 Derive one or more strategic paths through quantitative Fault Tree Analysis.

6.0 Recommend system design changes and/or monitoring as needed.

1.0 Describe the system

The first step is to describe the present system as accurately as possible. This is a neutral, descriptive stage, during which the analyst derives inputs from sources at many levels of the organization.

A number of writers have suggested ways of describing communication systems, particularly for the purpose of communication audits in organizations. Greenbaum (1972) has proposed a complex schema which includes external-coordinative, internal-coordinative, and interpersonal subsystems; and he further distinguishes between management information systems and personnel-interaction systems, activities which are centered in the individual, the group, or the organization, and the channels used, whether written, oral, or non-verbal.

The difficulty with most such descriptive methods, whether as comprehensive as Greenbaum's or much simpler, as that they do not lend themselves to the type of analysis which shows the network of interactions that typically exist in any communication system. We have found it helpful, therefore, to start with a system map, which uses some of the characteristics of a functional flow chart.

Before constructing a system map, the analyst must find answers to the following questions:

1. What is the mission, goal, or intent of the communication system?

2. Is the entire system to be analyzed, or one or more subsystems? In other words, what are the bounds of the system?

3. What are the constraints in the system, both external and internal?

4. What are the major functions present in the system for communication?

In its simplest form, the system map is similar to the function flow block diagram of Figure 2, without the feedback loops. Treating each of the rectangles as events in an operational system, outputs from Event 1.0 become inputs to Event 2.0, and so on. In this figure, the outputs from Event 2.0 become the inputs concurrently to Events 3.0, 4.0, and 5.0. All of these events must occur and produce outputs before Event 6.0 can take place. If the system design is such that the flow of information from 2.0 to 6.0 can go through <u>either</u> 3.0 <u>or</u> 4.0, <u>or</u> 5.0, this relationship is expressed with the juncture O instead of A. The map thus makes the distinction between serial events, concurrent events, and alternate events, or channels.

A further symbol may be added. If the system provides for binary decision points, they can be indicated as in Figure 3:

Fig. 3

This is read: Does Event 7.0 occur as a result of Event 6.0? If YES, the flow of events proceeds through 8.0. If NO, it proceeds through 9.0. At 9.0, it may be aborted, recycled back through the system, or some other decision may be made.

In a systems map depicting an operational structure, the events in the boxes generally show the flow of energy within the system, in the form of actions which lead to other actions or operations. In a communication system, the flow is of information. The map, then, becomes a graphic portrayal of those communication <u>channels</u> available within the organization. Subsequent stages of analysis can deal with types of messages sent and received, conditions under which the information flow occurs, characteristics of senders and receivers, and the like.

The important thing in this first stage is to make a graphic portrayal of the system, in as much detail as is necessary for further analysis. As the analysis proceeds through the subsequent stages, it may become advisable to alter the system map to accord with revised perceptions of the system. Other forms of mapping may be used as appropriate. For example, it might be advisable to map the actual flow of information spatially among the significant members of an organization, using office layouts, floor plans, and the like.

Another approach is to adapt the system's organizational chart, showing both vertical and horizontal channels as they actually exist. Figure 4 shows one such scheme, greatly simplified.

Fig. 4

A and B can exchange information, and B can interact with C, D, or E. In this organization, there is no direct communication possible vertically between A and C, D, or E, nor laterally among C, D, or E.

Regardless of the graphic schema used, these points should be kept in mind:

1. The schema should show the actual channels of communication that exist in the system, not the ones that occur on paper only. Any discrepancies between the actual system and the system as it is officially described should be noted at this stage. These discrepancies can be dealt with in subsequent stages.

2. The system portrayed may be a formal or informal one, but it should be one that is generally ongoing, and not simply fortuitous. This means that it will be mission or goal-oriented. Although the non-goal-oriented interaction and interdependencies of personnel in a system may be highly influential in contributing to the success or failure of the system, these non-standard aspects can be taken care of through a careful description of the communication roles played by personnel in

the total system.

It is possible to do FTA without a system map. This is often the case when an analysis is made of critical breakdowns that have already occurred in the system, and for which information as to contributing causes is available. Even in these circumstances, however, a rudimentary map of the system can immediately show whether the failures were due to weaknesses in system <u>design</u> or in inadequate <u>functioning</u> of a basically sound system.

2.0 Identify major stress points through Fault Hazard Analysis (FHA)

It often occurs that an examination of the system map by means of FHA will immediately reveal faulty design, potentials for information overload, lack of backup or monitoring subsystems, inadequate interface between subsystems, and the like. The FHA may also provide information for a major undesired event (UE) for the fault tree.

3.0 Perform Failure Mode and Effect Criticality Analysis (FMECA)

This is an optional step. In a full scale analysis, each component and function in the system is systematically examined for possible failure inputs, criticality of the inputs, and downstream effects of the outputs. Differential effects of failure events due to differences in system phases can also be considered. Interviews, questionnaires, observations on site, research data, examination of written and oral communications, and other applicable research methods can be used to derive inputs at this stage. The FMECA thus provides a systematic basis for deriving the failure events and their inputs for the next stage, qualitative fault tree construction.

4.0 Perform qualitative fault tree construction

A fault tree consists of events, interrelated by logic gates, and resulting in complex pathways. The analysis begins with the precise statement of an undesired event (UE) of critical importance. It may be the failure of the entire system, expressed as a failure of the mission; or it may be a failure identified with some subsystem or component. In any event, it stands at the top of the tree, and the analysis proceeds downward. Inputs to the UE become contributing failure events in a cause and effect relationship.

Before discussing the nature of the events, however, it is necessary to clarify the concept of logic gates. The heart of the fault tree approach, and that which differentiates it from other forms of analysis, is the use of logic gates to show the relationships among events. There are two principal kinds of logic gates, the AND gate and the OR gate. All other gates used are derivatives of these two.

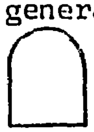
The AND logic gate is used when two or more events must coexist in order to produce the more general event. The AND gate is symbolized graphically by the symbol . In the fault tree, events related by an AND gate would be depicted as in Figure 5.

Fig. 5

This would be read: Events B and C must coexist to produce Event A; or, the output can occur only if the inputs B and C coexist. The mathematical equivalent of this is $A = (B \wedge C)$.

In behavioral systems, this relationship most commonly exists when a subsystem or component and one or more backup systems or components exist or are possible within the design of the system. This situation occurs much less frequently in behavioral than in hardware systems, and the implications of this will be considered later in this paper in regard to the interpretation of the tree.

The OR logic gate is used when, of two or more possible inputs to an event, any one alone could produce the output. The graphic symbol for the OR gate is . In the fault tree, events related by an OR gate would be depicted as in Figure 6:

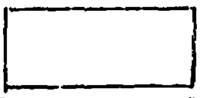
Fig. 6

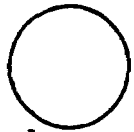
This is read: Either B or C alone will produce Event A. The mathematical equivalent of this is $A = (B \vee C)$.

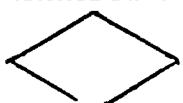
There are two general kinds of OR gates--the INCLUSIVE OR and the EXCLUSIVE OR. In the INCLUSIVE OR situation, either B or C or both could result in Event A. In the EXCLUSIVE OR situation, either A or B could produce C, but both A and B could not occur simultaneously.

With either the AND or OR gates, more than two inputs may exist. Variations of these gates allow for the specification of complex relationships--there are inhibit gates, priority AND gates which specify the sequence of events, matrix gates, and others. The analysis thus provides precise description of conditions as well as modes of relationships, all of which can be expressed mathematically and quantified.

The other set of basic symbols used in fault tree analysis depicts the types of inputs or events. Input and output events can be classified according to their nature. The following are the most commonly used symbols for fault trees:

Rectangle:  Identifies an event that results from a combination of less general fault events through an associated logic gate. All events symbolized by rectangles have additional development in the fault tree.

Circle:  Identifies a basic failure event that requires no further development. This could occur when the definition of an event is sufficiently explicit to satisfy the purpose of the analysis. It also occurs when there is a "primary" failure of a component, analogous to a power failure in a telephone system. The decision as to whether the event is a basic one or not depends somewhat on the perspective of the analysis. For example, if the telephone system itself were being analyzed, then events leading to a power failure would be traced in much more detail. However, if a telephone is considered one system component within an organizational communication system, a power failure might be considered a basic event requiring no further analysis.

Rhombus:  Identifies an event which is not developed further due to (a) lack of information, (b) very remote likelihood of occurrence, or (c) because time, financial or other constraints preclude further analysis. (This symbol should not be confused with the diamond used as a decision point in flow charting.)

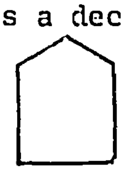
House:  Identifies an event that is normally expected to occur in the system as defined. When combined with other events, however, it might contribute to a failure event.

Figure 7 shows a rudimentary fault tree, which is read as follows: "Event A can be produced <u>either</u> by Event B <u>or</u> Event C. Event B can be produced only by the coexistence of Events D <u>and</u> E. Event C can be produced <u>either</u> by Event F <u>or</u> Event G or <u>both</u>." Event E is a primary or basic failure event, and Event F is an event that normally occurs in the system, but which can contribute to Event C. Events D and F require no further analysis.

Fig. 7

The "bottom of the tree" for any branch always will have events depicted by the circle, rhombus, or house. In this example, there are two branches and 3 levels of analysis.

For each given event, which in turn becomes a UE, failure events contributing to the UE can be derived from the FMECA, or by systematically asking questions regarding input, processing, and output failures; i.e., failures of a given component or subsystem may be attributable to failures of input from another part of the system, failures of processing within the component or subssytem itself, or failures of output to another part of the system. Inputs may be internal or external to the system, but in general, the more proximate the inputs in time or space to the failed component, the more powerful the analysis. If internal failure events are really due to events external to the system, they will usually show up at the points of interface between the system and its environment.

The relationship of the system map to FTA is clearly shown as a comparison of analysis in success space with analysis in failure space. Figure 8 shows this comparison when the system is such that the events proceed serially, Events A, B, and C being prerequisite conditions to Event D. In 8a the events are depicted in success space--i.e., for success of D, a single thread of events is necessary from A→B→C→D. In 8b the events are treated in failure space; that is, <u>failure</u> of D can be caused by failure of <u>either</u> A <u>or</u> B <u>or</u> C <u>or</u> any combination of them.

Fig. 8

Figure 9 shows another configuration, using both concurrent and prerequisite conditions for success. Diagram 9a shows the flow in success space. For success of D, the flow of events or information must go from A$\longrightarrow$B, then to C_1 and C_2 concurrently before D can occur. Diagram 9b shows the events as treated in failure space. Failure of D can be caused by failure of C_1 or C_2 or both. C_1 can be caused by the failure of A or B or both; C_2 can also be caused by the failure of A or B or both.

Fig. 9

Figure 9b clearly shows the "faulty" nature of a system in which all of the events allowed for in the system must occur, either serially or concurrently, in order to achieve system success. In such a single thread analysis, any event at the bottom of the tree becomes the same as the top UE. In a communication system, or subsystem, such a configuration would occur when the flow of information can proceed only through specified channels, with no alternatives available in case of breakdowns, malfunctioning, or overloads. This is particularly serious when the system does not provide an alerting or monitoring mechanism, causing the problems to multiply before corrective action can be taken.

Figure 10 shows a system flow that looks superficially like that of Figure 9, but which has important differences. Diagram 10a treats the events in success space: For the success of D, the flow must go from A$\longrightarrow$B, then either through C_1 or C_2, after which D may occur. Failure of D, as shown in diagram 10b, then will occur only if both failures of C_1 and of C_2 coexist. Failures of C_1 as well as C_2 may be caused either by failure of A or B.

Fig. 10

Because of the difference in logic gates at D, the fault tree in Figure 10b will have a different strategic path value from that of the tree in Figure 9b, even if the frequency and importance values assigned to the branches and the end events are the same in both trees. It should be apparent from Figures 8, 9, and 10, however, that even a cursory inspection of system map configurations will provide information as to the viability of the system, with consequent implications for changes in design and/or procedures.

In practice, of course, qualitative fault tree construction is not as neatly related to the system map as these diagrams would indicate. A thorough analysis will generate additional inputs to any one of the events on the map that are not apparent in the map itself.

Another point to note is that it appears from Figures 8, 9, and 10 that analysis for failure is simply the reciprocal of analysis for success. To an extent this is true, in that experience has shown that reduction of the likelihood of a UE occurring, through changing or monitoring the sequences of events on the primary strategic paths, will increase the likelihood of system success.

Recent work with FTA of complex systems, however, has shown that failure analysis gives perspectives on a system which go beyond the simple inversion of success space to failure space and back again. In fact, the FTA methodology itself appears to have a heuristic value, both for those participating in the analysis and the managers and other decision makers to whom the results and recommendations are communicated. It generates questions about the system which do not occur under the usual conditions of success analysis.

Additional support for this approach comes from the work of Herzberg (1968, 1971). It can be readily inferred from Herzberg's work that events that produce success, particularly in relationship to increased organizational efficiency, are not the precise opposite of those events that produce failure. They are two different areas for investigation. It is hoped that this knowledge will correct the neglect of failure analysis in the evaluation of organizational efficiency and communication.

In summary, qualitative fault tree construction proceeds in these stages:

4.1 State undesired event (UE).

4.2 Develop inputs for first level, i.e., "scope the top of the tree."

4.3 Relate inputs logically by means of logic gates.

4.4 Develop inputs for each first level event, using input-processing-output model.

4.5 Relate second level inputs logically.

4.6 Repeat steps 4.4 and 4.5 for each second level input to develop third level inputs.

4.7 Continue process for succeeding levels of fault tree development to depth of resolution desired.

Qualitative fault tree construction, then, constitutes a systematic "threading back" through the system. In this respect it is like PERT. The PERT diagram, however, is more similar functionally to the system map than to the fault tree. As a matter of fact, a PERT diagram might be used to describe a management information system where sequences of events in time, generally non-repeatable, are of crucial importance, as in the communication system that is a part of process or formative evaluation of complex research projects. The fault tree can then be based on the PERT, rather than on a system map.

5.0 <u>Derive one or more strategic paths through quantitative Fault Tree Analysis (FTA)</u>

5.1 Starting with the top UE, rank in order of relative <u>contribution</u> (or <u>importance</u>) of each of the failure events leading into it (i.e., each of the inputs), utilizing a consensus formation process such as the Delphi technique. (For a description of the technique applied to Fault Tree Analysis, see Stephens, 1972. More general sources are Helmer, 1966, Campbell and Hutchin, 1968, and a comprehensive bibliography compiled by the Research Management Group of AERA.)

5.2 For all of the inputs to a single event, determine the percentage <u>contribution</u> made by each event to the more general failure event above it, utilizing a consensus process. Percentages should sum to 100 for each event.

5.3 Repeat steps 5.1 and 5.2 for the inputs to each failure event, working systematically down through the tree.

5.4 Decide on a rating scale suitable for use in evaluating the <u>frequency</u> (or <u>likelihood</u>) of occurrence of failure events in the fault tree. (E.g., a scale of low, medium, and high might use ratings of .1, .2, and .4 respectively, indicating that a "medium" rating is twice as likely to occur as a "low" rating, and that "high" is twice as likely as "medium." These are nominal values only.)

5.5 Determine the appropriate <u>frequency</u> rating for <u>each event</u> at the bottom or lowest level <u>only</u> for each branch of the tree. The rating for each input to an event is determined independently of the other inputs for that same event.

5.6 Calculate strategic path values for the tree utilizing the judgments of relative contribution, frequency of occurrence, and logic formulas through the logic gates. (For formulas, see Stephens, 1972.)

5.7 Identify strategic paths of interest by inspection.

Probability as a measure of the chance occurrence of events is usually defined mathematically as (a) the area under a curve which is representative of the pattern of occurrence of events, (b) the relative frequency of occurrence of events in a stochastic process, and (c) the ratio of the number of ways an event of interest can occur to the sum of the number of ways it can and cannot occur. Strategic path values do not give probabilities in this sense, but they do represent a relative probability in the sense that they reflect measures of the occurrence of events in terms of how often those events might occur in the system (frequency) and how important they are if and when they do occur (relative contribution). The relationship of the probability formulas to logic diagrams is accomplished via Boolean algebra.

Although a computer program is available for deriving strategic paths (as well as for drawing the tree), the computations can be done by hand. On trees of more than 300-350 inputs, however, this process is too time consuming. Even without completing the quantification, however, much valuable information regarding the operation of the system can be gained by simple inspection of the tree.

It is not necessary for most of the team members engaged in qualitatively constructing the tree or quantifying it to know more than the rudiments of fault tree principles. The main requisite is a good working knowledge of the system under analysis. Team members should represent many different levels and functions within the organization, as the various "levels of visibility" afforded by different personnel will lead to perspectives differing in important respects. These perspectives are dealt with directly in the quantification process. Experience has shown that wide divergences of opinion can be reconciled without being ignored or subdued. Furthermore, the technique accommodates and utilizes both "hard" data and expert opinion.

An advantage of using an input-processing-output model within the framework of Fault Tree Analysis is that the analyst can account for intermittent or fortuitous events while putting the information within a context in which reliable judgments can be made regarding the importance of such events and their contribution to failures of communication. Moreover, by focusing on the components of the system and its subsystems, rather than on individuals or types of messages, a general picture will emerge as to the extent to which the system fosters purposeful, goal-oriented communication, or whether it sets up unnecessary barriers.

The degree to which a formal analysis is made will depend upon a number of factors--the amount of time available for analysis, the commitment of the organization to maximizing the communication system, the importance of the analysis to the organizational goals, and the perception of management of the general health of the system.

6.0 Recommend system design changes and/or monitoring as needed

The final step in FTA is to make recommendations based upon the strategic path analysis. These may include reallocating resources, installing backup systems, providing for monitoring of paths with high failure potential, redesigning subsystems, providing for improved communication at interfaces, or taking any other corrective action that seems advisable. Displaying the fault tree and discussing the strategic paths and their implications with personnel at various levels of the organization often will bring excellent suggestions for improvement and an increase in cooperative effort to work toward organizational goals.

History and Background of FTA

FTA is an operations research technique which has been used with signal success as a major analytical tool of system safety engineering on aerospace projects. The concept of FTA originally was conceived by Bell Telephone Laboratories as a technique for performing a safety evaluation of the Minutemen Launch Control System. Bell engineers discovered that the method used to describe the flow of "correct" logic in data processing equipment could also be used for analyzing the "false" logic resulting from component failures. (Haasl, 1965) The format was also well suited to the application of probability theory in order to define numerically the critical fault modes. Haasl points out that the Minuteman Safety Study was successfully completed using the new technique, and provided convincing arguments for the incorporation of a number of equipment and procedure modifications.

Further development of the analytical and mathematical techniques of Fault Tree Analysis in hardware systems has occurred principally in the Boeing Company, and since it was first introduced in 1961, attempts have been made to apply the technique to many different systems inside and outside the company. Some of these have been a model of the man/machine interface in a manned space system, and analysis of such problems as highway safety and vandalism in the schools. For further descriptions of the history and development, see Ericson (1970) and Stephens (1972).

Driessen (1970) reports the application of FTA (which he calls Cause Tree Analysis) to industrial accidents, infant falls, and the like. He pleads for a wider application of the technique both to system safety analysis, and to psychology and the behavioral sciences.

Although a limited amount of analysis of human factors has been attempted, as in the Boeing man/machine interface of a manned space system, until 1967 few attempts had been made to apply the technique entirely to behavioral systems. This was partly because trained analysts were mainly engineers concerned with system safety, and partly because no adequate method of defining strategic paths (called critical paths in hardware fault trees) had been demonstrated. The nature of behavioral systems makes hard probability data difficult if not impossible to come by, and such concepts as "time to repair" used in FTA hardware formulas have no exact human system counterpart.

Since 1967, however, the authors have successfully applied FTA to a number of educational, managerial, and research problems, (Stephens, 1972, Witkin with Stephens, 1968), and have taught the technique to others during a two-year EPDA project (Witkin and Stephens, 1972). Others have applied some of its principles without the use of logic gates (San Leandro Unified School District, 1970).

An important breakthrough for FTA of non-hardware systems came with the development (Stephens, 1972) of a new quantification scheme for deriving strategic paths through the use of Bayesian probabilities. The viability of strategic path analysis for management decisions in educational systems was demonstrated through Stephens' analysis of the vocational educational system of the Seattle public schools, which resulted in a major curriculum change.

Since that time, both qualitative and quantitative FTA have been applied by the authors, along with others who have taken FTA training, to other kinds of problems, including school district reorganization, a community college self study, and research project management. Applications in progress at the time of writing include the formative evaluation of a university instructional television research project (Butler, 1972), and the analysis of communication breakdowns in the management of an ESEA Title III project for deaf children. FTA is also being used as the principal management information system for Witkin's project in Auditory Perceptual Training, a research utilization project now in its third year. FTA will also form the basis for cost/effectiveness analysis of the various modes of implementing and adapting the project's instructional materials to various media and classroom environments.

Related Methodologies

Although the application of Fault Tree Analysis to analysis of organizations is of very recent origin, the concept of looking for actual or potential breakdowns is not new, and other techniques have elements which bear a superficial resemblance to FTA. The Critical Incident technique (Flanagan, 1954), developed mainly to identify good and poor performance on the job by focusing on the most memorably effective and ineffective behaviors of a particular person in that position, has been used to identify and formulate educational problems (Campbell and Markle, 1967), and to analyze the behaviors of school principals (Cooper, 1963). Although the technique was felt to be useful in identifying needs in school systems as inputs to problem formulation, the methodology did not go beyond the gathering and sorting of narrative statements.

Inoue (1972) has proposed a Cause and Effect analysis, a diagramming technique based on a systems model utilizing branching methods as inputs to various parts of the diagram. The analysis proceeds in a simple left-to-right continuum, from causes to effects, and provides for inputs from many sources along the way.

Interestingly enough, a claim which Inoue makes for C & E analysis also applies to FTA. He states:

> The advantages of using a C & E diagram in the coordination of multidisciplinary team efforts are several. First, the construction of the C & E diagram allows considerable flexibility in recording random ideas systematically. It has the same advantage that a computer enjoys with a random-access memory storage. Discussion may jump from one topic to another, and back again, without causing any difficulty in sorting and sequencing the list being compiled. (p. 11)

Although the FTA method does not encourage this kind of jumping around, it inevitably occurs in any group process. The FTA method used for generating inputs, however, tends to focus the thinking of the group on specifics and to organize all inputs within a systematic framework. Moreover, experience with very different kinds of fault trees (e.g., vocational education, research project management, community college assessment) has shown that the technique has other advantages in a multidisciplinary team effort.

1. It focuses expert knowledge and judgment from often widely disparate disciplines and functions on a common problem and furnishes a common language and perspective.

2. It can take into account both agreements and divergences on the inputs and their importance.

3. It allows for concentration on one area of interest at a time, but with the assurance that all other areas will be systematically dealt with.

4. By concentrating on the way the system operates, rather than on personalities, it introduces a non-threatening atmosphere and encourages a freer exchange of information among the members.

A network diagramming technique which approaches FTA more closely is the decision tree (Archibald and Villoria, 1968). The decision tree has been used in industry when an organization must make decisions about future plans based on incomplete information. The technique is based on the theory that no decision operates in isolation or even in a simple sequence, and it is assumed that any decision made at any time will be influenced by events that have happened in the meantime.

The decision tree utilizes a branching process to depict alternative solutions, with nodal points on each branch representing specific decision points at some time in the future. From each node issue more branches which specify the possible alternative results to be anticipated at each decision point based on varying future events. The costs of alternative future decisions can be specified, also.

Although decision trees appear not to be widely used in organizational analysis or in educational management, they have proved very effective in certain kinds of industrial planning. A much more sophisticated attempt to anticipate future needs through analysis of the past is described by John Wilkinson, a Senior Fellow at the Center for the Study of Democratic Institutions, in a recent article, "Retrospective Futurology" (Wilkinson, 1972). In it, he discusses the possibility of using high speed digital computers to assess the secondary effects of future decisions (as in city planning), based on "cultural trajectories" spanning 6000 years.

With the exception of the Futurology technique, which is still in its infancy, none of the techniques described in this section attempt the indepth analysis of FTA. As previously stated, the heart of the FTA approach, and the feature that distinguishes it from other network diagramming or C & E methods, is the use of logic gates. The advantage of logic gates is two-fold: (1) it permits the expression of the <u>relationship</u> among events--and these relationships may be expressed both graphically and mathematically, no matter how complex; and (2) it permits the prioritizing of sequences of events based on massive quantities of data. For example, the tree constructed to deal with management of the Auditory Perceptual Training project has over 440 inputs. The possible relationships could thus be expressed as 2^{440}. Without some method of systematically relating these events and prioritizing them, this quantity of information would be meaningless. The analysis resulted in the defining of 5 high priority critical paths, which have now become the foci for monitoring and process evaluation. Some research design changes were instituted, also.

Implications for Organizational and Communication Theory

Considerable attention has been given recently to the concept of communication audits and other methods of appraising the effectiveness of communication systems in organizations. These methods range from questionnaires administered to employers and employees, to extensive analyses based upon a thorough definition and description of the system and how it works. These analyses, however, are usually within a narrative or tabular framework. (Burhaus, 1972; Farace and Russell, 1972)

The close relationship between organizational communication and organizational effectiveness has been stressed by a number of writers. Greenbaum (1972) views organizations as

> . . .formal social units composed of motivated individuals, with personal and common objectives, involved in problem-generating activities that must be continuously coordinated; and this coordination is achieved, in large part, through the use of appropriate communication systems. (p. 3)

Franc (1974) states that "Accomplishment of organizational and programmatic mission is the real criterion for organizational communication." (p. 4) He adds,

> The more one looks into what are initially viewed as communication problems, the more overlap there seems with basic management problems. . .Better

> clarification of distinctions between communication and administrative breakdowns should help us develop indices for successfully predicting breakdown incidents before they occur. (pp. 20-21)

FTA has been developed, not only to predict breakdown incidents, but to analyze and prioritize the most probable modes of occurrence of failure sequences within an organization.

Hawes (1970) points out that one of the requisites of the survival-oriented organization is a change in managerial style. Instead of stressing stability in the organization, Hawes believes that

> . . .in a survival-oriented organization, the manager becomes a co-ordinator of "temporary" task-oriented groups of highly specialized professionals. His basic responsibility is to <u>identify potential problems</u>, <u>assess the nature of existing problems</u>, assemble. . . task groups. . .and. . .implement the information generated in those groups. (p. 5, emphasis added)

We have shown how FTA can be used to provide precisely the data needed by such a manager, leading not only to a pool of solutions, but a way of continually assessing the "real" problems and their contribution to preventing the attainment of objectives.

One hazard facing such organizations is information overload.

> In a closed, highly structured, bureaucratic system only certain types of information permeate its boundaries; the rest is systematically filtered out. The result is a minimum of overload but also a minimum of flexibility. In an open, loosely structured, protean learning environment a wide variety of information permeates the system's boundaries. The result is a maximum of information overload but also maximum flexibility. (Hawes, 1970)

Hawes adds:

> The dilemma confronting today's organizations is which information can be filtered to reduce unnecessary overload without, at the same time, crippling the organization's ability to adapt to an ever changing environment. (p. 9)

One of the advantages of the fault tree approach to analysis is that it can show precisely those primary modes of failure within an organization and its communication system which lead to information overload. In fact, alternate analyses are possible for the same system.

For example, a system which is closed, rigidly structured, with little openness to interaction with information outside its own boundaries, can be subjected to a FTA. Such a system will probably show a preponderance of OR gates, reflecting single thread paths of information with few alternatives or backup subsystems to provide for dissonant information. On the basis of the strategic paths generated by the analysis, alternate system designs can be postulated, the analysis can be run again, both qualitatively and quantitatively, and new strategic paths generated.

Although the quantitative data are nominal, and thus do not represent probabilities of occurrence of any of the paths, the fact that the strategic paths can be ranked, by inspection, in order of likelihood of occurrence, provides management information of a highly useful kind.

In fact, the use of FTA in itself is one way of coping with information overload. By designating those sequences of events within the system most likely to lead to the specified UE's, decisions can be made as to that kind of information which is most crucial for effective organizational functioning.

The methods of coping with information overload, of course, cannot be specified by FTA alone. FTA, however, could provide data for decisions as to methods of coping. For example, Miller (in Hawes, 1970) has identified eight coping strategies--omission, error, queuing, filtering, approximation, multiple channels, escape, and chunking. FTA can identify those types of strategies presently used in the organization, analyze the cause and event sequences that occur actually or potentially, and suggest better methods or combinations of methods.

A serendipitous effect of FTA on participating members of an organization has also been found. Without exception, those who have actively participated in working with the analyst to derive inputs for the qualitative and quantitative analysis have gained a new perspective of the system and have turned from somewhat passive members to active workers for system success. In one instance, in a large metropolitan school system, the FTA was so successful in engaging the support of the administration for a needed curriculum change, that the school board allocated over $200,000 additional to the area, at a time of stringent budget cutbacks. It might be added that the change was of a nature which would have been hotly fought in the past by the very people who became its proponents after working on the FTA.

An interesting feature of organizational systems has emerged in our work since 1967, both with FTA of hardware and of non-hardware systems. FTA was originally developed to determine the modes of occurrence and their probabilities of highly unlikely events. Since the aerospace systems are constructed with regard for a high degree of safety, predicted probabilities of occurrence of the critical path might be on the order of 3 in 1,000,000.

When the focus of the analysis shifts from hardware to behavioral systems and the interaction of people and information, the probability of the occurrence of any given sequence of failure events becomes very high. Typically, organizational systems are designed with built-in failure potential. The task then becomes one of sifting through all of the possible and probable sources of failure in order to identify and prioritize those sequences having the highest potential. It often appears that the first four or five strategic paths generated all have a high a priori probability of occurring in the system as it operates.

Observers and critics of the changing scene in organizational structure have proposed that, for survival purposes, organizations in the future must think in terms of processes rather than hierarchies (Hawes, 1970). FTA should certainly be considered a powerful tool for moving from the static organizational chart to the analysis of interlocking processes. It can focus not only on how the organization is designed to operate in respect to its communication processes, but on the way in which it actually does operate; and it identifies those sequences of events which must be monitored or changed in order for the processes to operate more effectively, both to accomplish the necessary tasks and to enhance productive relationships.

We have stressed before that a system approach to analysis must deal with the complexities and interdependencies which are an inherent part of any system, by definition. One characteristic of systems is that stress in any part of the system will eventually make itself felt in other parts, perhaps far removed from the stress point itself. It often happens, however, that a problem, such as a breakdown in communication, is perceived as having its source in one part of the system when, in fact, its "real" causes are elsewhere.

FTA is capable of dealing with such secondary effects of stress in the system, of spotting and analyzing redundant failure events which may have significant cumulative impact, and of defining interactions among events which appear to be unrelated. The quantification process adds power to the qualitative analysis in accomplishing this.

To sum up. FTA has been found useful as the principal analytic method under the following conditions:

--Whenever undesired events or concerns and factors contributing to those concerns can be identified;

--Whenever differing areas of expertise must be marshalled;

--Whenever involvement of the members of an organization needs structure and systematizing;

--Whenever a defensible approach to resource allocation within a complex system is needed;

--Whenever consensus as to what constitutes success in the system is difficult to obtain;

--Whenever formative evaluation is necessary;

--Whenever the primary and secondary effects of future decisions must be analyzed.

Organizations both private and public often make plans which appear highly successful in solving social problems, only to have disastrous secondary effects appear, sometimes 25 years later. In commenting on the need for sophisticated tools to predict such secondary effects, Wilkinson (1972) wryly states,

> . . .on the shaky assumption that you can't act intelligently to solve a problem unless you know something about the system of which it is a part, it may eventually turn out that a systematic stab at social problems will at least enable those who are burdened with responsibility to consider such problems intelligently.

It is hoped that more analysts concerned with organizational communication will consider using a system approach, including such promising techniques as Fault Tree Analysis.

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Figure 1

MODEL OF A SYSTEM

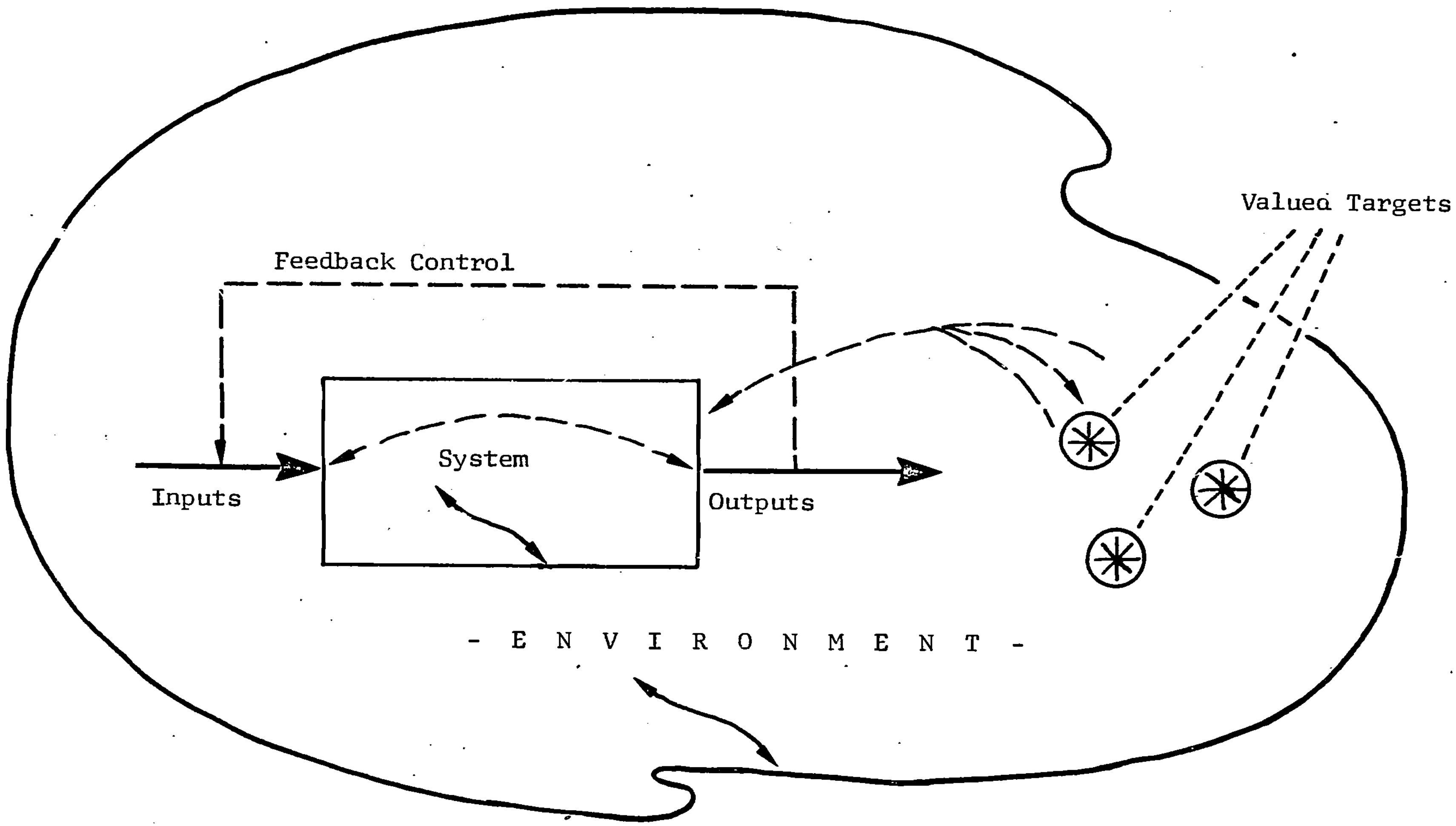


Figure 2

FIRST-LEVEL FUNCTION FLOW BLOCK DIAGRAM

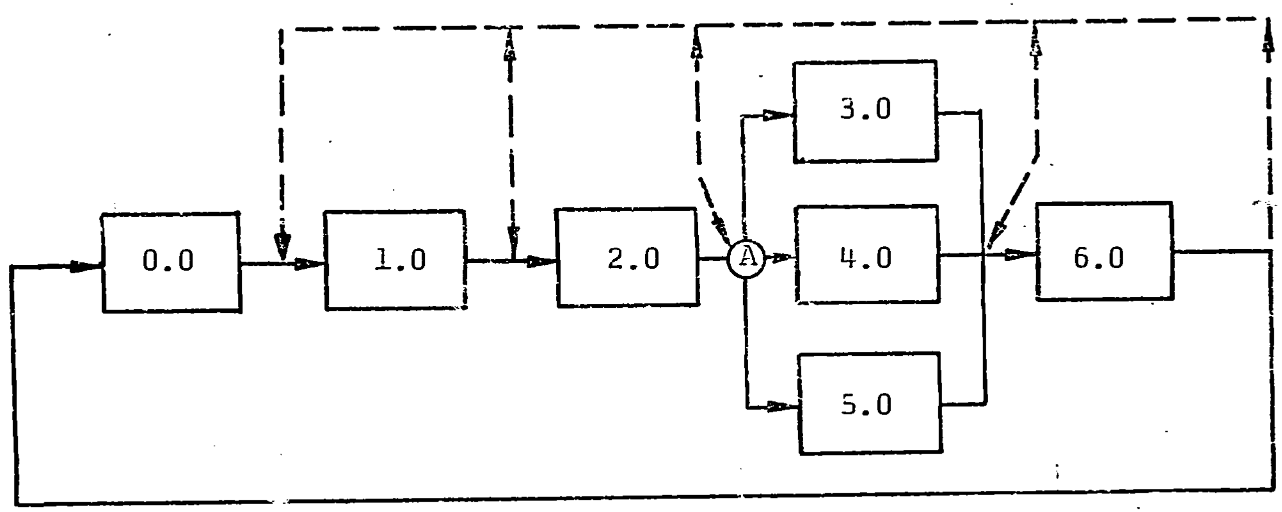


Figure 3

DETAIL OF A SYSTEM MAP

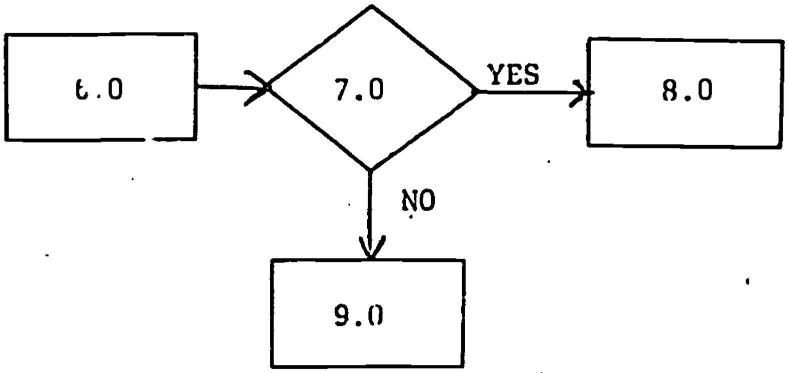


Figure 4

ORGANIZATION CHART SHOWING COMMUNICATION FLOWS

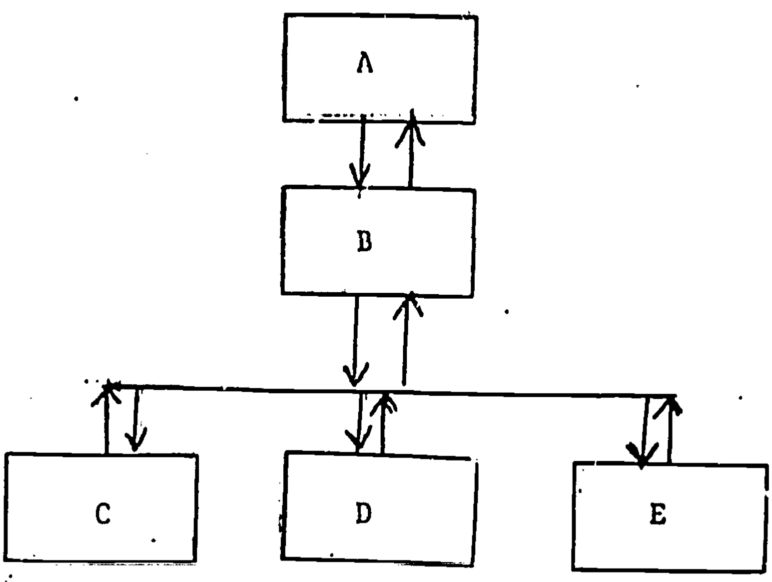


Figure 5

THE AND GATE

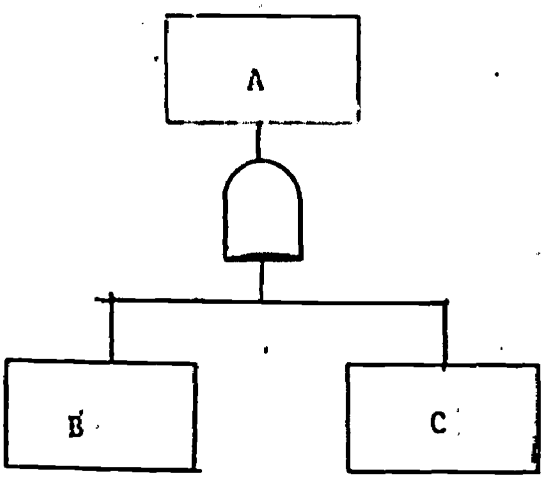


Figure 6

THE OR GATE

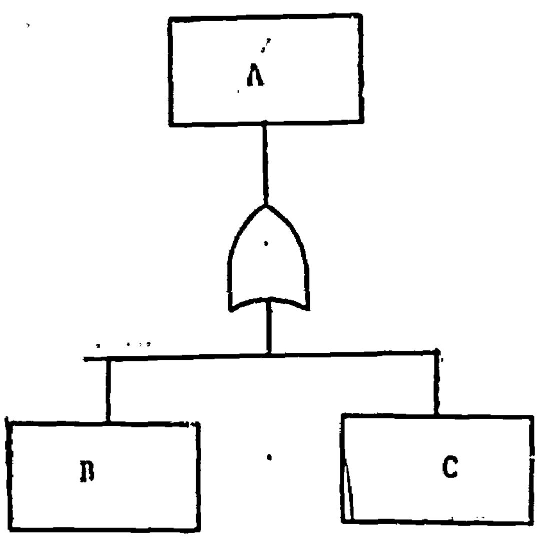


Figure 7

ILLUSTRATION OF A FAULT TREE BRANCH

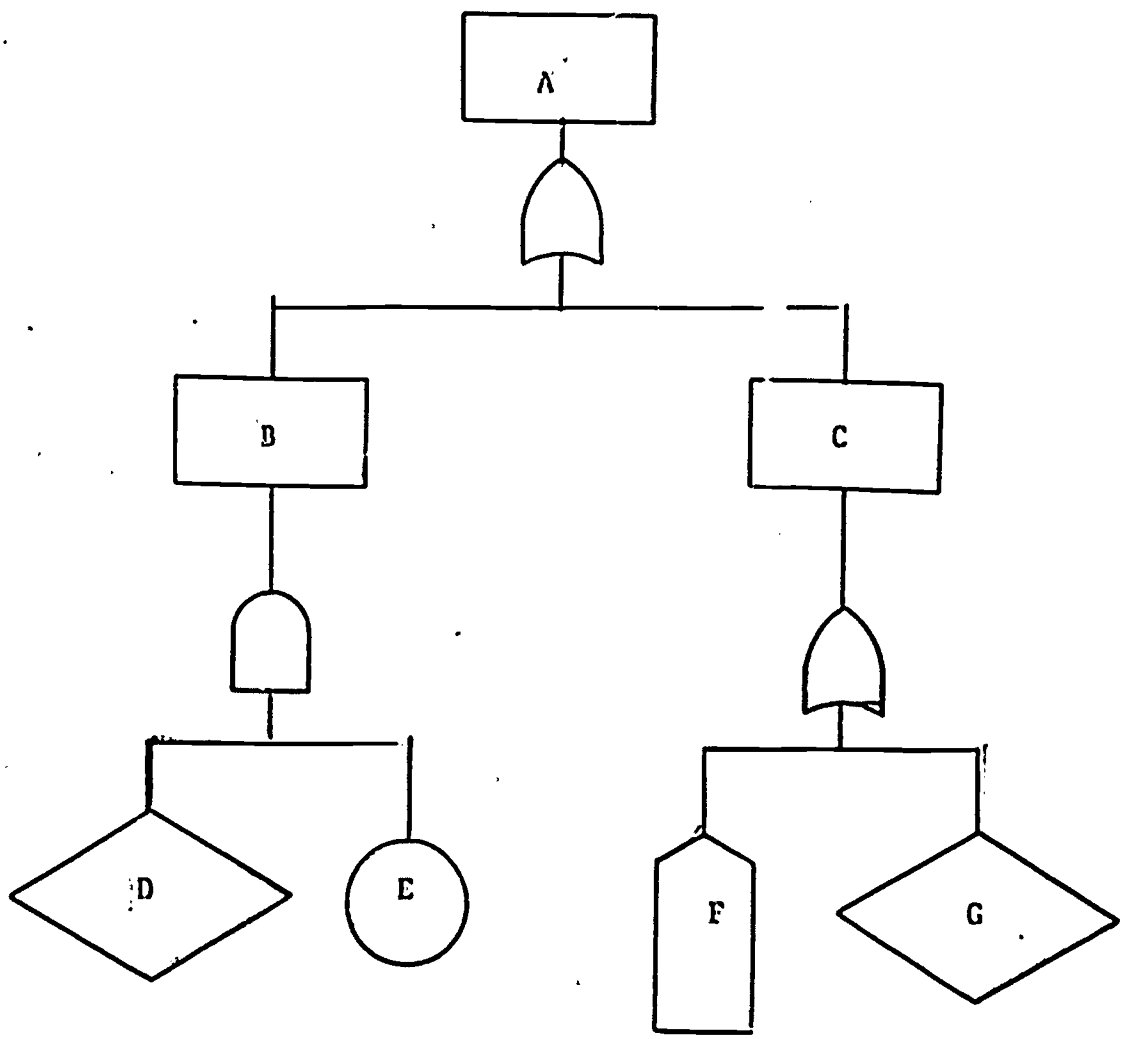
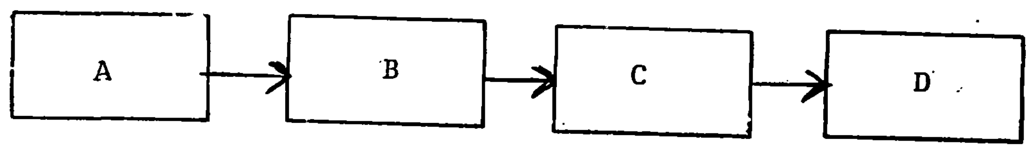


Figure 8

COMPARISON OF ANALYSIS IN SUCCESS SPACE WITH ANALYSIS IN FAILURE SPACE

FOR PREREQUISITE EVENTS IN A SERIES

(a) Success Space



(b) Failure Space

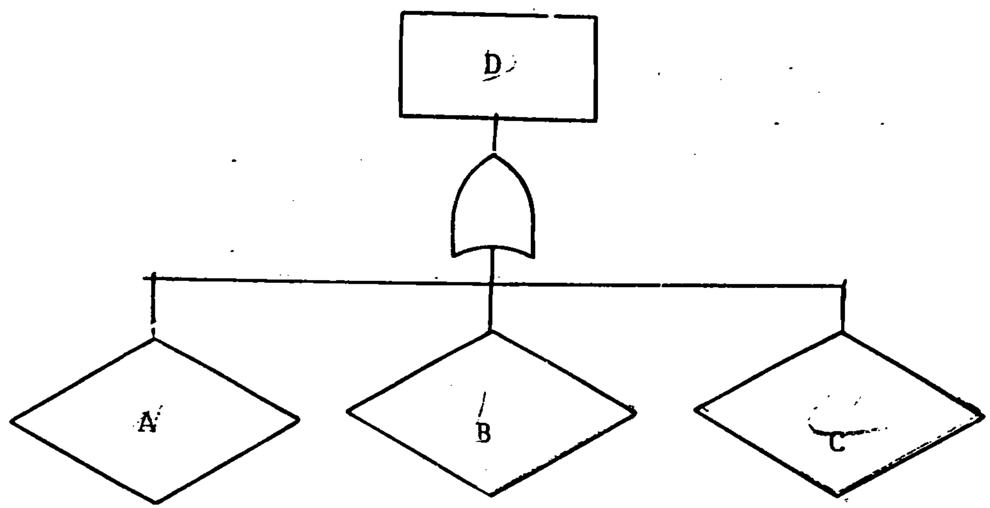
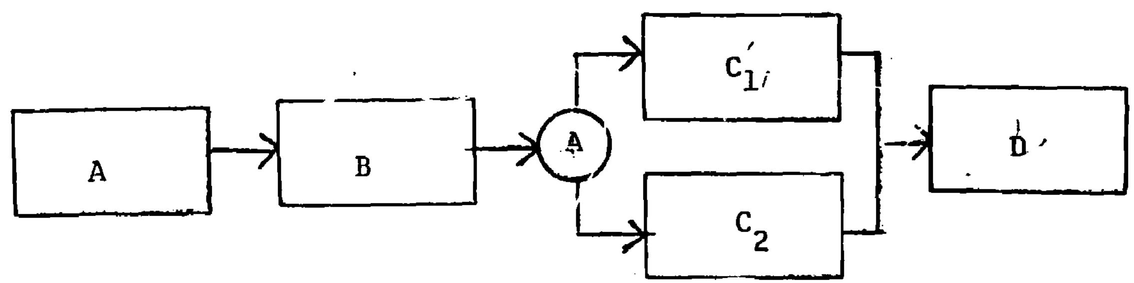


Figure 9

COMPARISON OF ANALYSIS IN SUCCESS SPACE WITH ANALYSIS IN FAILURE SPACE

FOR CONCURRENT AND PREREQUISITE EVENTS

(a) Success Space



(b) Failure Space

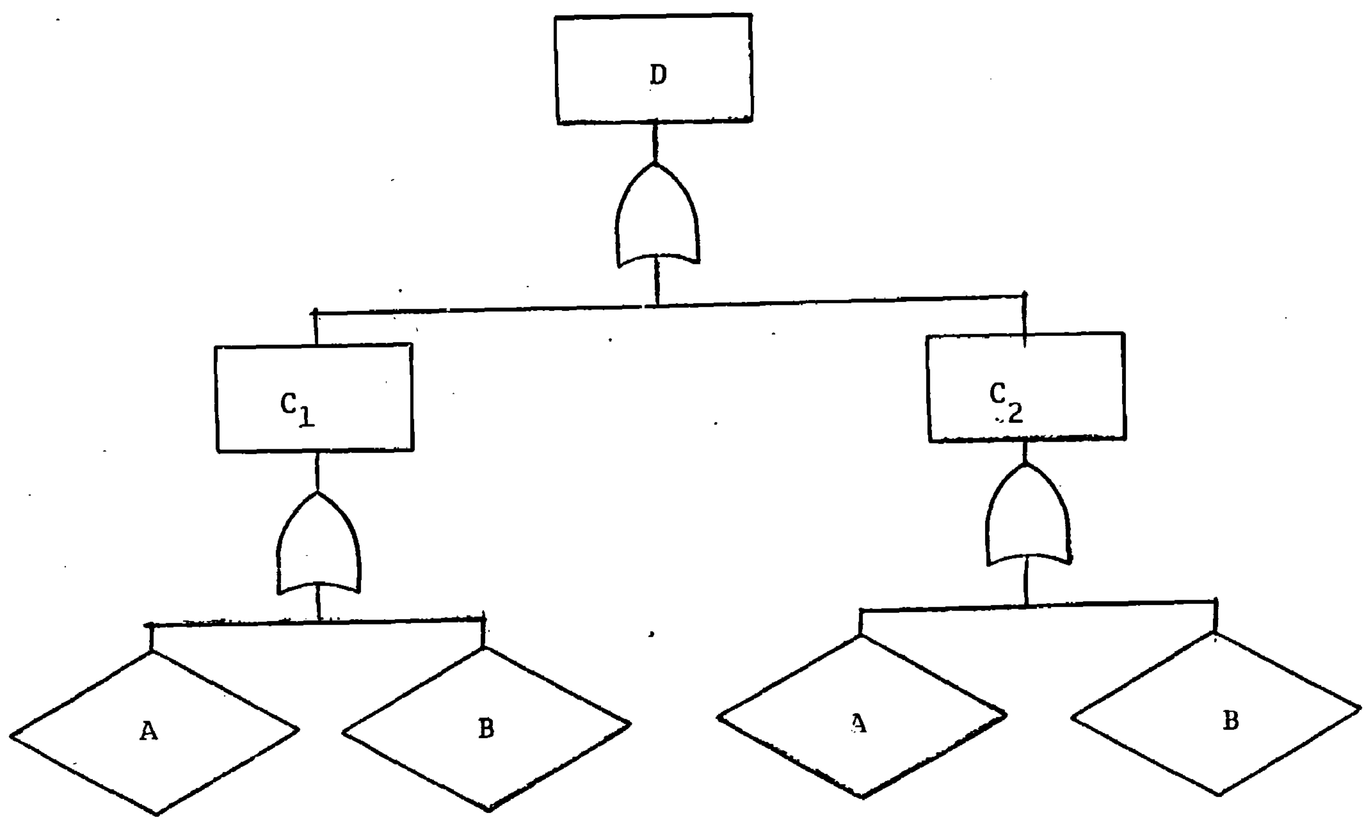
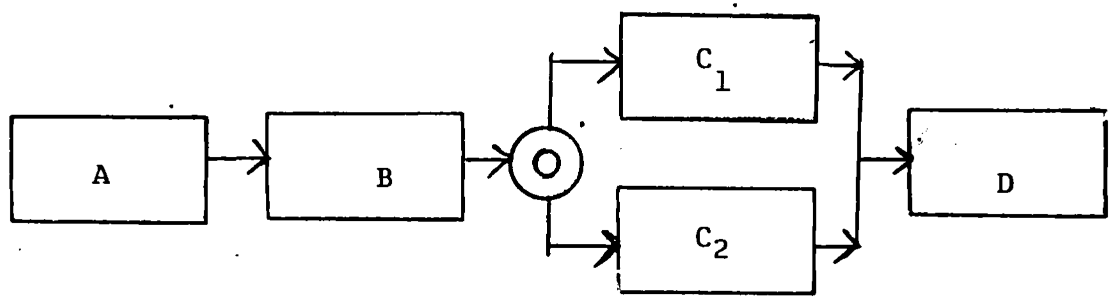


Figure 10

COMPARISON OF ANALYSIS IN SUCCESS SPACE WITH FAILURE SPACE

FOR SYSTEMS WITH ALTERNATE CHANNELS

(a) Success Space



(b) Failure Space